6.6 CONDUCTIVITY AND MOBILITY OF SEMI CONDUCTORS

Consider a semiconductor of length l, area of cross-section A in which n_e number of electrons and n_p number of holes flow when a potential difference V is applied. The total current I is given by

$$I = I_e + I_h$$

where I_e, the current due to flow of electrons is given by

$$I_e = n_e A e\, v_e$$

Here, e is the electric charge and v_e is the drift velocity of electrons. Similarly, if v_h is the drift velocity of holes, then

$$\mathrm{I}_h = n_p\, e\, A\, v_h$$

Hence,
$$I = n_e\, e\, A\, v_e + n_h\, e\, A\, v_h$$

or
$$\frac{I}{A} = n_e\, e\, v_e + n_h\, e\, v_h$$

or
$$J = e\,(n_e\; v_e + n_h\; v_h)$$

where
$$J = \frac{I}{A} \text{ is the current density.}$$

In terms of conductivity, J is the product of electrical conductivity σ and electric field intensity E. Therefore,

$$\sigma E = e\,(n_e\; v_e + n_h\; v_h)$$

or
$$\sigma = \frac{n_e\, e\, v_e}{E} + \frac{n_h\, e\, v_h}{E}$$

$$= n_e\, e\, \mu_e + n_h\, e\, \mu_h$$

where μ_e and μ_h are the mobilities of electrons and holes.

The mobility of electrons μ_e is greater than the mobility of holes. Thus $I_e > I_h$.

The electrical conductivity of N-type semiconductor is determined by using the relation

$$\sigma_N = N_d\, e\, \mu_e$$

where N_d is the number of donar impurity atoms per unit volume.

Temperature dependence of electrical conductivity : Starting from temperature of zero kelvin to 10 K, the conductivity increases with rise in temperature. This rise is due to the increase in the number of conduction electrons due to ionisation of donars in N-type semiconductor. The conductivity becomes maximum when all donars are ionised.

The graph between $\log_e \sigma$ and $1/T$ is shown in Fig. 6.17. From point B in the graph, the conductivity decreases with further rise in temperature upto point C. This is because of decrease in the mobility μ_e with increase in temperature. After point C, the conductivity increases sharply till point D.

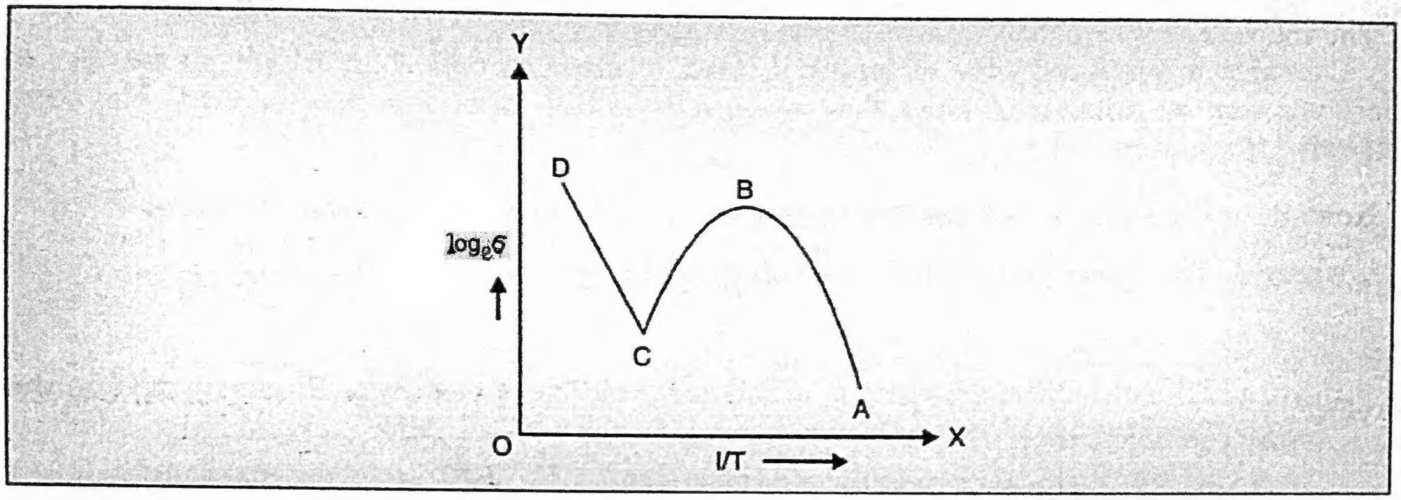


Fig. 6.17

The electrical conductivity of a P-type semiconductor is given by

$$\sigma_P = N_A \, e \, \mu_h$$

where N_A is the number of acceptor impurity atoms. The variation of conductivity with changes in temperature is similar to that for N-type semiconductor

Conductivity of Intrinsic Semiconductor

In case of intrinsic semiconductor (germanium or silicon), the number of conduction electron is equal to the number of holes, *i.e.*,

$$n = p = n_i$$

where n_i is the intrinsic concentration of electrons or holes in the semiconductor.

Thus, the conductivity σ_i of the intrinsic semiconductor is given by

$$\sigma_i = e\,[n_i\,\mu_e + n_i\,\mu_h] = e\,n_i[\mu_e + \mu_h]$$

Conductivity

The conductivity of a semiconductor is different from a metal in the respect that in a semiconductor the charge carriers are ***electrons*** as well as ***holes***, *i.e.*, a ***bipolar device***. On the other hand a metal is unipolar (conduction takes place by ***electrons*** only).

5.11-1 DOPING AND ITS EFFECT ON THE CONDUCTIVITY OF A SEMICONDUCTOR

1. Doping

Addition of impurity atoms to intrinsic semiconductor material is called ***doping*** and the impurity used for doping is called ***dopant***.

In addition to the intrinsic carriers generated thermally, it is possible to create carriers in semiconductors by purposely introducing impurities into crystal. This process, called doping, is most common technique for varying conductivity of semiconductor.

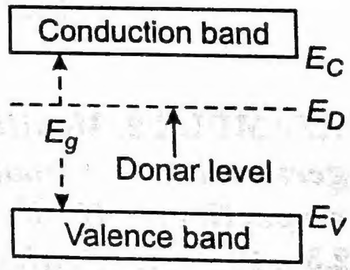
By doping, a crystal can be altered so that it has a pre-dominance of either electrons or holes. Thus, there are two types of doped semiconductors, N-type and P-type. When a crystal is doped such that the equilibrium carrier concentration n_0 and p_0 are different from intrinsic carrier concentration n_i, the material is said to be extrinsic.

2. Effect of Doping on the Conductivity of a Semiconductor

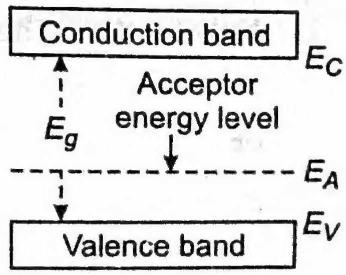
Consider a germanium crystal is doped with phosphorus. The four outermost electrons of phosphorus atom form a tetrahedral bond with four germanium neighbours. The fifth electron remains loosely bound with its parent atom. The energy of fifth electron is close to the conduction band. The energy level of this electron is known as donor energy level E_D as shown in fig. (18a). The fifth electron moves in the electric field of germanium crystal. As a result, the conductivity of semiconductor increases.

Similarly, the doping of silicon crystal by aluminium atom is shown in fig. (18b). In this case holes are majority carriers. The acceptor energy level E_A is shown in fig. (18).

Therefore, when impurities or lattice defects are introduced into an otherwise perfect crystal, additional levels are created in the energy band structure, usually within the band gap. Therefore, conductivity increases.



(a) Energy level diagram showing donar energy level.



(b) Energy level diagram showing acceptor energy level.

Fig. 18.

5.12 MOBILITY OF SEMICONDUCTOR

The steady state velocity attained by the charge carrier under the influence of applied electric field E is called as drift velocity and is denoted by v. Therefore,

$$v \propto E \quad \text{or} \quad v = \mu E$$

where μ is a constant of proportionality and is called as ***mobility.***

$$\therefore \qquad \mu = \frac{v}{E} = \frac{\text{m / sec}}{\text{V / m}} = \frac{\text{m}^2}{\text{V-sec}}$$

So, the unit of mobility is square metre per volt-sec.

The mobility μ of a charge carrier varies as T^{-m} over a temperature range of 100 to 400 K.